Utah Lake: A Few Considerations

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The following observations and insights concerning Utah Lake have been developed during my nearly 50 years in Utah Valley as a professor, researcher, environmental engineer, consultant and local citizen. At the end of this "white paper" I have included a review of some relevant water quality and pollution issues, a tabulation of Lake water and salt balances, and plots of Lake levels and salinity since 1930.

Utah Lake overview. Utah Lake is a major physical feature and unusually complex lake eco-system covering about half of Utah Valley's floor area— When "full", it averages about 9 ft. deep and covers about 150 square miles. The Lake is integrally linked to us and the Valley. Attitudes towards the Lake range over an interesting spectrum—from "priceless beautiful Lake" to "worthless swampy pond." Intense competition to use and benefit from the Lake for many different purposes is confronted by its rich ecological community that contests many use and development ideas. The use of Utah Lake resources will always feature complexity and controversy due to the eco-richness, importance and value of these resources. Overall, public consensus favors persistent pollution-control efforts and continuing reasonable steps to protect the Lake and its tributaries. Recently, however, one feels increased public sensitivity for wise use of public funds to avoid expensive pollution control programs/projects that exhibit diminishing, even negative, marginal returns, especially when coupled with low overall benefit /cost ratios.

What is Utah Lake's natural condition? Utah Lake is a shallow, eutrophic, basin-bottom Lake in a semi-arid region. Sediments thousands of feet deep lie beneath much of the Lake. The Lake is naturally turbid, slightly saline and eutrophic (very biologically productive). In most of its physical and chemical aspects (e.g., water quality), it appears that the Lake has not dramatically changed since its hydrology and ecosystem "stabilized" as Lake Bonneville last receded about 10,000 years ago—as the last ice age ended as the climate slowly warmed in early stages of the current natural, cyclic, global-warming period. It's sobering to realize that over past hundreds of thousands of years, huge lakes have cyclically filled our Great Basin, often accompanied by massive glaciers creeping down from the mountaintops—with dry valley land and habitable conditions, similar to those found today, occurring occasionally between inhospitable climatic periods.

Utah Lake exists in a shallow subbasin formed by massive, geologic block movements that define the topographic geology of this area. Evidence indicates that in our immediate area, the last major earthquake and faulting episode occurred some 8,000 years ago. This significant geologic faulting deepened the Main Lake—making it as much as 20 feet deeper in some areas but generally some 3 to 10 feet deeper. In the intervening 8000 years, some 15 to 20 feet of sediments have accumulated in deeper areas of the Lake—less in the shallows. Hence the Lake is now likely a little shallower than it was before that major faulting episode. If that 'basin-deepening' fault movement had not occurred, the Lake would have largely filled in by now and would exist only as swampy lowlands along an upward extension of the Jordan River.

Since pioneer settlement about 160 years ago, indications are that water quality in the Lake has remained fairly constant. However, land use changes, water diversions and introduced plants and animals have caused significant changes in ecosystems in and around the perimeter of the Lake, as well as along many inflowing tributaries. Concurrently, water quality deteriorated some in most tributaries; however, this deterioration is moderated considerably by natural cleansing processes as these waters flow along their courses and into the Lake.

Naturally, Lake outflow rate was controlled by Lake water level relative to a natural rock sill that crossed beneath the Jordan River about 7 miles downstream at Indian Ford Park. Had larger fault-movement occurred during the big earthquakes some 8000 years ago, the Lake might not exist at all or might be deeper, depending on the relative vertical movement of the lakebed as compared to this bedrock sill. The top few feet of this rock sill were removed in the late 1980s as engineers dredged the Jordan River channel to increase Lake outflow capability, following several years of very high lake levels and attendant shoreline flooding. The Lake reached its highest recorded level of the last 160 years during this very wet period in the mid-1980s.

Nowadays, when Lake outlet gates are fully open, discharge rate down the Jordan River is determined by Lake water level relative to the elevation of irrigation diversion works about a mile downstream from Indian Ford. The channel dredging and sill removal increased the unimpeded outflow rate about 100% at Compromise elevation—from about 500 to 1050 cubic feet per second (cfs); 400% greater at one foot below Compromise—from about 200 to 800 cfs, etc. Compromise elevation (4489.04 ft) is the Lakes "legal" full elevation—the water elevation at which outlet gates must be opened fully so additional rise in Lake elevation is as small as possible to minimize additional flood damages around the Lake.

Why does the Lake level fluctuate so much? Ans: Unfortunately, it is nearly impossible to keep the Lake within a couple of feet of a desired elevation, even over a few months, since the amount of water required is too large to quickly bring into or move out of the Lake, particularly during the Spring and Summer months. Evaporation is the factor that causes much of the natural fluctuations. Most of the annual evaporation of about 4 feet occurs during the June through September period, largely after the spring runoff. Note that 4 feet of evaporation represents about 300,000 acre feet of water which is about one-third of lake-full volume and about one-half of the annual average water inflow. During droughts even if most upstream stored waters could somehow be commandeered from the "owners" it would still fall short of the amount needed to keep the Lake full. During wet cycles, the Lake's restricted outlet and small downstream gradient in the Jordan River limit the discharge rate; therefore during times of relatively large inflow, lake level rises as water is stored in the increased depth. Over time, excess stored water is discharged as outflows finally equal and then exceed decreasing inflows.

Under "natural" conditions, Lake levels commonly varied 2 to 4 feet within a given year due to the natural cycle of large spring-runoff followed by much smaller inflows during the rest of the year. About 150 years ago, only a few years after initial pioneer settlement, efforts began to control discharges and operate the Lake as a shallow storage reservoir to be able to release water on demand for summer irrigation of downstream agricultural lands. Periodic flooding of land around Utah Lake caused by the stored water was strongly protested by Utah Valley shoreline land owners. These conflicts led to the establishment of "Compromise" Lake elevations—the level where Lake outlet gates must be fully open to allow unimpeded outflow. Also, many Lake tributary water diversions occur. These two factors of outlet control works and upstream storage and use typically add additional annual Lake level fluctuations of 2 or 3 feet—thus increasing annual Lake level fluctuations to a range of some 3 to 6 feet.

Over several-year-long wet to dry cycles, lake level drops as much as 15 feet from its highest to lowest levels. When at its lowest point at the end of a prolonged drought, the Lake becomes very small, receding to the middle of the lakebed where it is a pond only 3 or 4 feet deep with no natural spill-over outflow. Wet-dry cycles vary in magnitude and length; recently they seem to be bottoming about every 20 to 30 years. As the Lake goes into a dry cycle, it drops lower and lower with annual fluctuations continuing in the 3 to 6 feet range. At the bottom of major droughts, annual evaporation often exceeds annual inflow and the Lake continues to shrink even though there is no Jordan River outflow.

Why is Utah Lake slightly salty at times? Ans: Evaporation concentrates the dissolved minerals (salts) in the Lake. During an average year, about half of the Lakes inflowing water evaporates. Evaporation averages 4 feet annually and precipitation averages 1 foot, so net evaporation is about 3 feet—a net loss of about 230,000 acre feet a year. This is a huge volume of water. It would supply a city of about 1 million people or irrigate about 70,000 acres of farmland. This evaporation also nearly doubles the Lake's total dissolved salt (TDS) concentrations compared to the average TDS in inflowing waters. During the peak of wet cycles, outflowing water averages less than one year of residence time in the Lake; while at the bottom of dry cycles, detention time increases to several years.

An interesting major salt source is numerous relatively-small mineral springs that flow into the Lake. These mildly thermal, slightly salty springs—with TDS typically 1500 mg/l to 7000 mg/l[1]—are associated with numerous geological faults that encircle, as well as pass under, the Lake. These mineral springs are only about 5 percent of the inflowing water but contribute about 27 percent of the total salts. Most of these mineral springs are small, scattered, often diffuse, and most are submerged. These factors make it infeasible to undertake large scale collection and export of these brackish waters to reduce salt loadings to the Lake.

Interestingly, nearly 30% of inflowing dissolved salts precipitate as solids in the Lake and become the bottom sediments. Calcium and Carbonate constitute most of these precipitated salts. The net result of these factors is that average TDS in Lake is still more than two times higher than most inflowing waters, but these TDS levels are still only moderately high from a water quality and beneficial use point of view. Over the years, through major wet and dry cycles, average TDS in the Lake varies about fourfold, from about 500 mg/l to 2000 mg/l. Lake plant and animal communities seem well adapted to this salt range and these TDS variations do not seem, in and of themselves, to cause them problems.

Modeling simulations of the Lake, based on estimated conditions in pre-settlement times as compared to current conditions, indicate that average TDS concentrations are some 35% to 45% higher than existed in the pre-settlement Lake more than 160 years ago. This increase is mainly due to (1) diversions of tributary waters that reduces the inflow of low-salt waters and also reduces Lake flushing and (2) increases in TDS concentrations in tributary waters due to upstream water use. Again, this 35% to 45% salt increase does not seem to have caused significant problems to the Lake's ecosystem.

[1] Utah Lake averages about 900 mg/l over the last 80 years; for reference, sea water is about 35,000 mg/l.

During average to wet periods, Utah Lake TDS levels are within to slightly higher than drinking water guidelines. Over time, given the fluctuations in TDS levels, these levels make the water poor to unacceptable for drinking water—after "conventional" treatment. The high TDS levels during prolonged dry periods makes Lake water unacceptable as a "conventionally-treated" drinking water without salt reduction, via treatment or dilution with higher quality (low TDS) waters. Unfortunately, the highest Lake TDS levels occur during dry cycles when additional sources of drinking water are most needed. "Natural" biological residues also make these waters rather difficult and expensive to treat to produce drinking water. When appropriate advanced treatment is used, these treated waters are acceptable for drinking water, but the necessary advanced treatment would cost some 2 to 3 times more than for conventionally-treated drinking water. The Jordan Valley Water Conservancy District reports that costs for the most promising advanced treatment for salt removal (reverse osmosis) would be about the same as costs for both developing and treating other low TDS water sources using conventional treatment plants. Someday, if a dramatic need for additional drinking water occurs, large-scale treatment of Utah Lake water might become economically competitive. But for the time being, the cost of advanced treatment is too high for Lake water to be used as a major source of drinking water. In the future, it is likely that we will see additional interception of inflowing higher quality water, particularly groundwater, both along the Lake shoreline and along lands adjacent to the Jordan River, as important sources of additional drinking water. This approach could collect considerable water that could be used directly for municipal use without conventional treatment, but some would need that treatment.

For traditional irrigation in Utah, crops begin to experience significant salt damage from "salty" water when TDS levels exceed about 1,500 mg/l. The State's 1,200 mg/l irrigation water quality standard is occasionally exceeded in Utah Lake during prolonged droughts. During the worst part of drought cycles—usually 1 or 2 months in late summer—TDS levels have occasionally reached 2000 mg/l or higher, making this water essentially unusable for irrigation since TDS this high causes considerable damage to most crops. As indicated in Figure 1, TDS levels have been above 1500 mg/l about 3.5% of the time since 1930 (40 of 996 months.) Most of these months occur during the Sept-Dec period, after the main irrigation season. Although salinity damage to crops irrigated with this water is an ongoing threat, it appears to be a modest one if good irrigation practices are followed.

Why is Utah Lake so dirty, muddy, and sometimes stinky? Ans: Utah Lake is naturally "dirty" primarily due to the formation of mineral particles (precipitates) from salts in the Lake itself; coupled with the re-suspension of these flocculent bottom sediments by frequent, high waves on this shallow Lake.

The result is a milky gray-brown to a milky gray-brown-green color of the Lake much of the time. The natural precipitates are largely Marls, consisting largely of calcium carbonate mingled with lesser amounts of other minerals including considerable Silica and Phosphorus. Although eroded upland soils carried by larger tributaries are often the dominant sediments at their mouths, overall these tributary sediments contribute only a small portion of the total sediments deposited in the Lake. Thus, bottom sediments contain largely precipitated Marl minerals combined with relatively small amounts of soil sediments carried by inflowing streams and an even smaller amount of aquatic plant and animal detritus.

The Lake salt balance (see Table 1 at the end of this paper) shows that about 65% of inflowing Calcium and 55% of inflowing Carbonate (shown as Bi-Carbonate) precipitate in the Lake. On average this is about 92,000 tons of precipitates per year—for the total Lake area this is about 2 inches every 100 years. The other major dissolved ions largely remain in solution and are carried by the Jordan River towards the Great Salt Lake. In the Lake, deeper areas actually fill in somewhat more rapidly than do shallow areas. This due to more total precipitates from the larger volume of overlying water and migration of sediments from near-shore shallows where wave agitation re-suspends the flocculent sediments almost continuously. Over time re-suspended sediment tends to migrate to deeper waters, resulting in filling rates in the Main Lake of some 3 inches per 100 years.

In addition, Utah Lake is eutrophic—meaning overall biological growth and biomass is very high. Growth and decay of plant and animal life sometimes result in "swampy" conditions. Such conditions are moderate in Utah Lake (considering its very high biological productivity) due to its well-mixed, well-aerated nature. But at times and in some locations aesthetics suffer, anoxic zones develop and bad odors are generated. This natural problem is sometimes intensified by human-caused pollution.

How polluted Is Utah Lake? Considering the Lake's basin-bottom location and "rich" biological nature, its overall water quality is good. However, the Lake was not, is not, nor can it be, a "clear" Lake, largely because of its natural mineral precipitation and its wave-stirred nature. Interestingly, the Lake has excellent natural capacity for degrading and stabilizing both natural and human-caused pollutants. Its high oxygen levels, along with its naturally high pH, are favorable for removing and stabilizing many pollutants, such as organic debris, and precipitating and binding Phosphorus and heavy metals, e.g., Mercury and Lead. Even during the 45 years or so that Geneva Steel discharged its treated process waters into the Lake, during the 1940s to 1990s, significant water-quality deterioration was not observed except occasionally in the vicinity of Geneva's larger discharges.

For the Lake and most of its tributaries, there is a dearth of long-term water quality data. Most water quality data have been collected rather sporadically over just the past 40 years. The Lake is large and has numerous tributaries, most of which are rather small and many are fairly difficult to locate and access. This makes comprehensive tributary measuring and sampling efforts difficult, time-consuming and costly. The Lake also has a large groundwater inflow that is difficult to identify, quantify or sample. Nevertheless, a few Lake hydrological and water quality studies have been completed. These studies indicate that overall Lake water quality has changed very little over the last 60 years and in some parameters it has significantly improved—remember that prior to about 1950 most sewage, storm runoff and industrial wastes received little, if any, treatment before being dumped into the Lake.

Constant vigilance is required to avoid serious Lake pollution problems. Since the Lake is downstream of many human activities in Utah Valley, too frequently tributaries are illegally used as convenient dumps for garbage and trash that sometimes contain rather nasty polluting materials, some of which are carried into the Lake Although many polluting discharges have cleaned up via better treatment and management, we shouldn't erroneously believe that we have solved all of Utah Lake's pollution problems—from time-to-time illegal dumping or emerging pollution issues arise. For example, in 2007 State agencies conducted surveillance testing of Utah Lake fish and found violations of allowable Polychlorinated Biphenyl (PCB) levels in some fish species—notably bottom-feeding species, carp and channel catfish. Subsequently they issued a health advisory containing recommended consumption limits on these species.

In 2008, an intensive survey by the State of water and bottom sediments at the mouth of main tributaries and below wastewater effluent discharges failed to locate any current or recent PCB sources—the PCBs initially detected are probably a long-term carryover in bottom sediments from spillage or illegal dumping many years ago when the long life and polluting impacts of PCBs were not generally recognized. Given the extremely low levels of PCBs that triggered the health advisory, it might be argued that risk of injury or death is far greater in driving to the Lake than in eating fish caught there. However, the important point is not this particular pollutant or advisory, but rather the point that prevention and elimination of pollution whenever feasible is a wise policy, particularly the control of pollutants at their "throw-away" point of origin. For most exotic pollutants of concern in our Nation today, cleanup and restoration are often monumentally more costly than initial costs for proper waste disposal and pollution prevention.

Are algae in Utah Lake harmful? Algae are a natural and vital part (base) of aquatic food chains—they might be thought of as the grass in aquatic ecosystems. Algae grow abundantly in Utah Lake thus supporting a very productive biological system, but sometimes excessive algal growth occurs. These algal "blooms" cause water quality and habitat quality problems analogous to problems caused by tangles of plants and weeds on land. Some algae found in the Lake, particularly during the late summer or early fall, are cyanobacteria (blue-greens) that can be particularly troublesome and even toxic at times. When present in large amounts (blooms), algae sometimes causes complete dissolved oxygen depletion as a bloom dies away and decomposes. Toxins from decaying blue-green algae sometimes reach levels that harm, or even kill, other aquatic organisms. In fairly rare cases, these toxins can even kill large animals when they drink water containing elevated concentrations of these toxins.

A good indicator of past water quality conditions in a lake comes from identifying types and numbers of tiny diatom algae (their shells) deposited in the layered bottom sediments laid down over hundreds of years. Studies of sediment cores from Utah Lake indicate that types and relative amounts of diatom algae have not changed significantly over the last few thousand years. Since algae types and relative numbers are rather sensitive to changes in water quality and other aquatic conditions, consistency in types and amounts of diatom algae is strong evidence that environmental and water quality factors have been rather constant in Utah Lake for at least a few thousand years.

Should Phosphorus control be a high priority for Utah Lake? Ans. No! Very high levels of nutrients (Phosphorus, Nitrogen, etc) flow into Utah Lake—substantial parts of them are from natural sources. The concentrations of Phosphorus and Nitrogen flowing into Utah Lake are not directly toxic or poisonous to man or higher animals, but they are **10 to 15 times** the loadings that would normally trigger persistent, major algal blooms. However, closer scrutiny of the Lake's algae-growth dynamics indicates that high nutrient levels in Utah Lake is a moot point since, overall, algal growth is largely limited by the Lake's natural turbidity, i.e., light limitation appears to be the controlling factor on algal growth most of the time. Thus high levels of Phosphorus, Nitrogen, and other trace nutrients that occur at times in the Lake are of little pertinent concern since most of the time they are not the controlling factors as to the amount of algal growth—low light availability is. This is in contrast to clearer lakes where such high nutrient levels would typically cause massive algal blooms and many water quality problems.

But, for a moment, let's assume that someone still insisted on trying to reduce nutrients to "limiting" levels. This would require removal of over 90 percent of "nutrients" from tributaries and wastewater treatment plant discharges. In addition to extensive and costly agriculture and land use control programs in the drainage basin, the advanced treatment systems for nutrient removal from wastewater discharges would cost hundreds of millions in facility costs and tens of millions per year in ongoing operating costs. Some suggest that since we don't know whether nutrient control might be effective, we should initially use less expensive facilities to remove perhaps 50 to 80 percent of the nutrients and add the more extensive and much more expensive facilities later if needed. For Utah Lake, this seems folly since only about 70% of the total nutrient loading comes from wastewater treatment plant discharges. Even 100% removal of nutrients in these plants would most likely not reduce the overall Lake nutrient loadings sufficiently to make limiting to algae growth—in fact it is unlikely that even an extensive basin program using best available practices and technology would be able to reduce nutrient inputs to Utah Lake to a level low enough to significantly reduce algae growth in the Lake.

Nutrient-control effectiveness and benefit-cost issues are major issues in this case, since advanced wastewater treatment is very expensive compared to conventional wastewater treatment. For example, in Utah Valley costs for advanced wastewater treatment to remove about 90% of sewage phosphorus would be well above $300 million for facility construction costs plus additional tens of millions each year in operating and maintenance costs—resulting in utility costs for wastewater treatment more than double current levels. If Nitrogen removal were added, costs could nearly double again—a staggering cost, particularly in this case where benefits would likely be small or even nonexistent. Some people say that if the "government" or someone else will pay most of the costs then we should do it because "we are doing the right thing", in spite of the staggering costs and low probability of significant benefits. Isn't the proliferation of this kind of thinking a major factor in current financial distress across the Nation and around most of the world?

With respect to nutrient levels from the Lake into the Jordan River, high biological uptake and the chemically-binding nature of the Lakes chemistry and sediments combine to make the Lake a very effective system in reducing Lake-water nutrient levels to moderate levels—before flowing into the Jordan River. Consequently, large reductions in nutrient loadings to Utah Lake would likely not result in significant reductions in nutrient levels in the Jordan River, since residual concentrations are largely a function of chemical- equilibria levels in the Lake, not the amount that comes into the Lake.

Best Management Practices to control nutrients from agricultural sources, land erosion, storm runoff, etc, commonly concurrently reduce levels of both nitrogen and phosphorus; but treatment systems for sewage and industrial wastewaters require specific advanced treatment processes tailored for each nutrient. Therefore, when nutrient(s) reductions are considered for wastewater discharges, careful scientific evaluations are needed to specifically identify the relative importance of phosphorus and nitrogen in the overall bio-productivity of the waters considered, and which of the two, if any, should be controlled.

Another interesting point regarding nutrients is that many lakes in Utah are more nitrogen-limited than phosphorus-limited—this likely the case in Utah Lake. Some 70 years ago, early scientific research on nutrient loadings and lake productivity was largely done in areas of the world where phosphorus was generally the limiting nutrient to overall algal growth. Thus phosphorus concerns dominated the early scientific studies, the literature and subsequent nutrient-control efforts. More recently it has become evident that many lakes, particularly in alpine and arid areas, are nitrogen-limited. However, in nutrient-control programs, even when Nitrogen is more limiting (when Nitrogen to Phosphorus ratios are below about 10), Phosphorus reduction is usually still important to try to reduce Phosphorus to limiting values to discourage blooms of nasty, nitrogen-fixing, blue-green algae which tend dominate in eutrophic lakes during the late summer and early fall.

In summary, high nutrient loadings are likely insignificant for Utah Lake water quality overall, since growth-limiting, natural turbidity is widespread and persistent. Chemically-binding reactions and precipitation of phosphorus is likely also at play to make phosphorus limiting at times, when the waters are clearer during calm weather episodes lasting more than a couple of days. In tributary waters and isolated bays, high nutrient levels may or may not cause excessive algal growth and related water quality problems, depending on conditions found in specific areas.

Would Utah Lake be clearer if it were deeper? No! If deeper, the Lake would experience less wave-stirred sediment turbidly and thus likely be a little clearer during early spring and late fall, but turbidity from increased algae growth during spring into the fall would likely be much higher than the decrease in sediment turbidity. This situation would often result in a "pea soup" of algal growth during much of summer and early fall; and a major deterioration in lake quality and habitat—the most damaging effect would be increased episodes of oxygen loss during the explosion and decay of excessive algal blooms. Aquatic life stresses, high turbidity and bad odors are some of the problems accompanying excessive algae.

Incidentally, beneath the winter ice, clear water is often found since the flocculent sediments have largely settled to the bottom and light limitation caused by the ice-snow cover and lower water temperatures usually limit algae growth to low levels. However, in early spring, when the ice breaks up, water temperatures increase, waves quickly stir the bottom sediments; sunlight spurs algae growth and turbid conditions again prevail.

What Lake depth would likely trigger the problems mentioned above? Ans: About 15 feet or deeper (Currently, the deeper parts of the Lake are 10 to 14 ft deep when the Lake is full). Summer thermal stratification is the condition where warmer surface water overlies deeper, significantly colder water. This condition inhibits vertical mixing in the water column. Often aesthetics, water quality and habitat deteriorate significantly when persistent stratification occurs, particularly in eutrophic lakes. In Utah Lake, significant summer stratification would be expected in areas deeper than about 15 feet. Currently, the Lake does not experience persistent stratification—i.e., it is shallower than 15 feet and is well mixed; thus most of the time it escapes the oxygen-depletion problems that plague deeper eutrophic lakes.

More on stratification *(skip to next section if not interested)* In this climatic region, when clear, ponded water is deeper than about 20 feet, summer thermal stratification is common and often persistent—the top 10 to 20 feet of surface water does not mix with bottom waters for weeks or sometimes even months. During this stratification/bottom-stagnation, ongoing natural decay of accumulated organic debris at the bottom often results in loss of oxygen—First at the bottom and then upward in the overlying water. Under these conditions water at the bottom usually becomes stagnant and septic. These cesspool-like conditions stress or kill normal aquatic organisms and sometimes even kill fish if they can't find refuge areas still containing oxygen; such refuge areas are often near the surface or in areas of inflowing streams or springs.

In turbid lakes, thermal stratification can occur in a little shallower water; since turbid waters absorb more sunlight energy (heat) nearer the surface—so persistent summer thermal stratification can occur in turbid lakes in areas as shallow as 15 feet or so. Therefore in Utah Lake if any large area were dredged to depths of about 15 feet or deeper, persistent summer stratification would likely occur and trigger water quality and habitat problems that were previously rare in the Lake. Note that waves 2 or 3 feet high impart significant stirring energy down to a depth of about 12 to 13 feet. So when such waves occur, as they normally do at least each week or two on Utah Lake, stratification breaks up as waves mix the water.

Under ice cover, water stratification can occur even in very shallow areas. Low oxygen results when microbes deplete the oxygen as they decompose the organic debris. The worst oxygen loss occurs in shallower areas that have little, if any, circulation or local inflows. Under these conditions winterkill of fish and other aquatic organisms often occurs. This problem sometimes occurs to a limited extent in some of the more stagnant bays and inlets of Utah Lake. It is generally not a problem in the Main Lake, since (1) organic debris from summer growth largely degrades during fall months before ice cover develops, and (2) in addition to numerous surface inflows, many small springs issuing from the Lake's bed contain oxygen and also foster local circulation.

What maximum dredged depth might be acceptable in Utah Lake? Ans: About 17 feet.
To avoid summer Lake Stratification and its attendant problems, most of the Lake needs to be shallower than about 12 feet from early summer into the fall. Initial depths of about 15 feet in deeper parts in the late spring would, after normal drawdown, result in depths shallower than 12 feet into the late summer and fall. When full, deepest parts of the current Lake are 13 to 14 feet deep; the Lake averages about 9 feet deep. Its average depth (and water volume) could be increased some 50 percent if most of the Lake were dredged to be 16 to 17 feet deep. If only a relatively small area were dredged deeper than surrounding areas, the dredged area would still be turbid since it would continue to experience chemical precipitation. More importantly, water circulating from other areas would carry additional fine suspended particles to the dredged area and dredged areas would tend to fill back in rapidly since its relatively quiescent bottom water would foster a more permanent bottom accumulation of suspended sediments. In addition, large scale dredging is likely not feasible for a variety of ecological, engineering, and economic reasons. For example, dredged bottom sediments are clayey—when exposed to the air to dry, they shrink, crack, and become very hard, but when wet they swell and become mucky.

The massive amount of dredged muck would be another major challenge. If the entire Lake were dredged an average of just two feet deeper, the dredged material could cover an area 5 miles wide and 5 miles long to a depth of about 10 feet. But proactively, this material could be used to construct islands with total area of perhaps 7 square miles--requiring about 35 ft of initial fill that would be about 25 feet above the Lake bottom after a few years of settlement. This would result an island some 10 feet above a full Lake.

In summary on dredging, if areas of the Lake were deeper than about 17 feet in the late spring, Lake water would be clearer in the spring; followed by increased algal growth during the late spring and summer—caused by more light availability due to decreased turbidity. These algae blooms would likely cause some oxygen depletion problems and bad odor events during die-off. Most of these areas would likely become biologically-dead zones at the bottom most of the time.

Could islands be constructed in Utah Lake? Construction of wildlife-reserve, residential and recreational islands in the Lake, perhaps with some of them linked together by causeways or bridges, is appealing to some people. Sale of some of the constructed islands for residential and commercial use could provide hundreds of millions of dollars to fund the island-building projects and perhaps other Lake development, recreational, and environmental-enhancement projects. One or more islands reserved as wildlife refuges with limited recreation use would be great wildlife (and ecological) assets—rubble and rock shorelines could be used to enhance fisheries; the open land would could host numerous plants and animals. Lake-bottom sediments could be used for most of the needed fill material; top soils would need to be added for vigorous growth of grass, trees and other vegetation. After island construction, a few years of settlement would be needed before beginning facility construction. Initial fill would need to be some 25 to 30 ft above the Lake bottom, to order to give final, well-settled bottom sediments and fill materials with ground levels at least 10 ft above the full-lake elevation.

Could a road causeway(s) or bridge(s) be built across Utah Lake? *Yes! Crossings could* be built, but numerous, difficult environmental, engineering and financial problems exist. They would be major engineering and construction challenges and very expensive!—likely costing several hundreds of millions of dollars for a major crossing near the middle of the Lake.

Long anticipated suburban growth is continuing on the west side of the Lake. Many feel that this growth would accelerate considerably if more direct accesses were available to economic hubs on the east side. Build a road across the Lake? Can it be done?—Technically, yes. Practically and economically—It would be very difficult, since the bed of Utah Lake is a very poor foundation. If a fill causeway were used for a highway, it would need a very wide base (several hundred feet wide) or would need to be placed on driven piles. Both methods would be very expensive; bridges would cost even more. The roadway surface would need to be at least 6 to 8 feet above the highest Lake level to protect it from wave action, and to also protect it from major ice-sheet movement. (Occasionally, in late winter as the ice breaks up, wind-driven ice sheets can stack up 10 to 20 feet high along the shoreline or even move inland for several hundred feet.. However, this condition is rare and short-lived—perhaps a few hours every few years).

When loaded with the weight of a fill causeway, the lake bed under the causeway would settle several inches a year for many years. Of course, the settlement rate would decrease over the years as underlying sediments compacted. Uneven settlement would occur in places and result in an undulating road surface; problems of pavement cracking and breakup might be persistent. In addition to these problems, two or three shorter bridges or many very large culverts are needed along a fill causeway to allow for good water and aquatic biota circulation through the causeway to minimize adverse impacts on the Lake's ecosystem and recreational use. Likely the best solution both structurally and environmentally would be a bridge roadway, supported on pilings driven into the Lake bottom, perhaps used together with structural floats if the sediments are not sufficiently strong for piles alone to support the bridge. Engineering studies would determine how deep piles would have to be driven into the Lake bottom—perhaps 50 to 100 ft.

Also, at perhaps two locations, higher spans would be needed for up to medium-size sail boat passage—the keels of larger sail boats are too deep to operate in this shallow lake.

A generally north-south causeway/bridge across Provo Bay would have less-challenging foundation problems than across the main Lake, since bottom layers there contain more stable soils, particularly more sand and gravel layers, than under the main Lake. However, if a dike causeway were used to control water levels in Provo Bay at levels much different than the main Lake, the project would need a large hydraulic and pumping station(s) component—flood bypass channels would have to be built for Hobble Creek and perhaps other tributaries. Pumping stations large enough to pump flood-year water over the dike would be very costly.

Why are trout no longer abundant in Utah Lake? Bonneville Cutthroat trout, along with several other species—notably Whitefish and Suckers—were abundant in Utah Lake until about 1900. This Cutthroat was a large fish, with many weighing more than 10 lbs. Over-fishing, competition from introduced fish species, and interferences with stream spawning and migration cycles caused by dams and diversions for irrigation, resulted in low trout numbers after about 1900. Intensified stresses hit the greatly reduced trout population during the 1930s drought when fish struggled to survive in extremely low levels of warmer and warmer water in both the Lake and its tributaries. The combined stress factors eliminated the Bonneville Cutthroat from Utah Lake. Similar factors continue to challenge other remaining native species in the Lake, notably the “endangered” June Sucker.

Re-establishment of large numbers of trout in Utah Lake is very unlikely—it would require major changes in other fish species now in the Lake and large hatchery-based stocking to maintain good populations. Remember, however, that the Lake has very large populations of other fish in this prolific warm-water fishery. Overall, Utah Lake’s fishery is greatly underused—two of the Lakes fish species are under a limited-consumption advisory, but most knowledgeable people have no concerns with eating these fish unless they are a very frequent part of one’s diet.

Since June Suckers are currently listed as an endangered species under the Federal Endangered Species Act, continuing efforts to protect and restore them are major considerations in Utah Lake management. As part of restoration plans, projects are underway to greatly reduce the Carp population. The Lake’s huge Carp population is a major stressor and disruptor in the ecosystem. They have devastated rooted aquatic vegetation; and in several ways contributed to significant degradation of the aquatic ecosystem, particularly in the Lake’s shallows, inlets, and bays. Recently (2012), the Lake contained an estimated 6 to 8 million adult carp. Even after the removal of several million Carp over the last 3 years, they are still by far the dominant fish in the Lake.

The most feasible carp-control plan appears to be a continuing, “targeted” net harvesting for several years to greatly reduce carp numbers and bring them into better balance with the rest of the ecosystem. The long term effectiveness of this harvesting is debatable but it seems to be making favorable headway. A large reduction in Carp will likely not result in discernable changes in water quality but should result in other improvements in the Lake’s ecosystem, particularly in bay and near-shore areas, resulting mainly from re-establishment of native aquatic vegetation—many otherwise favorable habitat areas have been largely devoid of native aquatic vegetation for many years.

Some experts and many other observers question the long term wisdom and economic feasibility of efforts to "re-balance" native species and altered ecosystems. Questions as to our ability to actually accomplish the hoped-for results, the value of these results, and large costs often associated with trying to achieve restoration-preservation goals, give rise to serious value and cost/benefit issues. This is the case in Utah Lake where many people feel these issues should be more openly and carefully debated and considered before additional tens of millions of dollars are spend on attempts to protect this endangered species. Sometimes ongoing external funding and local vesting push detractors into a "politically incorrect" corner from where they find it difficult to raise feasibility and cost issues, or to generate balanced, serious discussion on them.

The invasive "problem" plant—Phragmites. An introduced, invasive water plant, Phragmites, has become huge problem in Utah Lake. It has spread throughout most of the Lake's shallows. Phragmites is a tall reed plant that chokes out other aquatic plant life and its debris fills in shallows rather rapidly, thus damaging and reducing aquatic habitat. This exotic plant grows prolifically in shallows along the shoreline. Uncontrolled, it crowds out nearly all other aquatic plants and forms an almost impenetrable mass of growth. It does great damage to the Lake ecosystem. Initially, it occurred mainly in the Saratoga area (NW corner) of the Lake but it is now found essentially around the entire Lake. Trial efforts have been underway for several years to develop control techniques and plans; "elimination" is very difficult and unlikely, even if a "natural" bio-control method is found. Utah County Weed Control personnel have energetically attacked the Phragmites problem and have developed control methodologies that promise considerable success, but they need resources to continue in a rigorous and persistent manner year after year or else Phragmites will be a major disaster in the Lake's natural ecosystem.

Why not fill in or dike off much of Utah Lake and use reclaimed lands for agriculture, land developments and additional wildlife habitat? At this point in our national experience, most lake and marshland areas are considered too valuable to allow further significant encroachment or destruction; therefore, current environmental laws and requirements make it very difficult to dike or fill shoreline and wetland areas. Though very unlikely, if at some point diking and dewatering were to be done to reclaim land, only the Provo Bay area has bottom sediments (soils) somewhat suitable for farming, but Provo Bay is also one of the most important wildlife areas and mitigation would be more difficult. The rest of the Lake has clayey, Marl-calcium-carbonate sediments that are not suitable for farming or most other uses without very extensive stabilization and enrichment.

Major environmental issues would arise with projects of this type. Given current environmental requirements, stabilized water levels would probably be needed to support the large marsh and wetland areas and would likely result in little, if any, additional land acreage for farming or development, as well as little, if any, water savings from reduced evaporation. Also, diked areas might suffer up to several feet of flooding for a few months about every 30 years or so during the peak of wet cycles. Flooding would occur since the cost of dikes high enough to isolate diked areas from high water levels in the main Lake, along with the cost of standby pumping or bypass channels for tributaries to keep the diked area water levels low, would be excessive.

Why aren't there more boat launch and recreation areas at Utah Lake? Ans: Lake levels over the years are rather variable and unpredictable. Around much of the Lake, particularly along north, east and south boundaries, shoreline-lakebed slope is rather flat—only about 1 to 2 feet per 1000 feet out into the Lake. Consequently, along much of the shoreline, boat access to open water is a major problem without dredged access channels and harbors since the natural water shoreline moves in and out over large distances with relatively small depth changes. Thus facilities positioned at normal high-water, lake-edge locations must dredge channels some distance out into the Lake for boat access during dry cycles. Conversely, during wet cycles, they are confronted with water several feet higher than desired. These depth fluctuations are a major obstacle to long-term boat use on the Lake; particularly for larger motorboats and sailboats. The main lake provides only about 10 feet of reliable depth when the lake is "full" but during drought periods depths are often much shallower. E.g., during the last 50 years about 20 summers experienced depths less than 8 feet, and for 10 years depths were less than 6 feet. In the future, environmental and ecological needs, water storage rights, and ongoing wet and dry meteorological cycles will likely result in depth fluctuations about the same as in the historic past. These fluctuations will continue to pose serious Lake access and flooding challenges to most shoreline facilities.

Are major ecosystem improvements feasible in the Utah Lake? This issue is very complex! Successful major ecosystem restorations and improvements tend to be extremely difficult to formulate and very expensive to implement, both in direct project costs and lost opportunity costs for competing uses. Many of the pressures on bird and animal populations come from factors other than the Lake's water quality and in-lake habitat. For example, restoration of the endangered June Sucker depends more on additional favorable spawning and brood areas in the streams and rivers and reduced competition from other fish, than on pollution reduction or improved water quality.

Shoreline vegetation and habitat will likely benefit from current water development plans and projects of the Central Utah Project, which will reduce the magnitude and frequency of extremely high and low lake levels. The magnitude and frequency of Lake level fluctuations are important in re-establishing shallow water vegetation, such as cattails and bull-rushes; hopefully future scientific studies will help clarify this potentially important aspect of habitat improvement. Control of the "pest plant" Phragmites is also a crucial issue in this recovery.

With reasonable attention to ecosystem preservation and enhancement, Utah Lake can continue to support very rich and diverse plant and animal communities. Some enhancing habitat and water quality changes are possible, but it's not possible to make it into a "clear" Lake. Appropriate emphasis on preserving and enhancing its ecology does not preclude additional development on and near the Lake. True environmental sensitivity, not just popular, politically-correct actions of the day, will always be extremely important in any projects.

Do we need more Utah Lake research? Yes! Scientists, engineers, and others always want more data, information and understanding than is currently available. However, good research is an ongoing process; hopefully one without repeated major starts and stops, and especially one without mostly short-term efforts with long inactive periods in between. Realistically, resources are simply not available to fund ongoing, long-term, intensive research activities on large numbers of lakes and rivers. But Utah Lake is indeed one of those unique lakes, where developments, projects and decisions involving the Lake will address actions involving hundreds of millions, or even billions, of dollars in future decades—and on into the future as development continues in Utah Valley.

I passionately believe that information and knowledge gained from a significant, ongoing Utah Lake research program would result in savings far in excess of costs! Establishment of a permanent Lake research station would be a wise, much-needed course of action.

What will Utah Lake be like in the future? Water quality in Utah Lake is not likely to change significantly in the foreseeable future as long as wastewater treatment, agricultural pollution control, and other pollution control efforts are continued at least at current levels. A Total Maximum Daily Load (TMDL) water quality study, conducted by the State of Utah, is still open. This study's purpose is determining whether additional pollution control is needed to protect Lake beneficial uses. The TMDL study was initiated several years ago because of occasional violations of Phosphorus and TDS guidelines for the water use classifications assigned to the Lake. It is unlikely that significant new pollution control restrictions or requirements will result from the TMDL study results since the first phase of the study did not find any significant problems associated with occasional exceedances of TDS and Phosphorus "limits".

Regardless, Utah Lake will be neither clear nor deep nor bordered by expansive clean, sandy beaches—although some sandy beaches exist and might be expanded. It will continue to be a shallow, turbid, slightly saline, eutrophic lake that is largely bordered by muddy and marshy wetland areas. Hopefully all of us recognize that in addition to its economic uses, it is an extremely valuable ecological and recreational resource. Wetland protection laws, threatened native species, natural flooding and other environmental impacts will limit development near the shoreline. Causeways, bridges, and additional dikes will probably be built sometime; perhaps even some islands will be constructed. Near-shore development and use constraints are likely to be less restrictive on the west side than on the east, since on the west side the shoreline is steeper and more stable, and fewer extensive wetlands exist there. East side zones also exist where development conditions are somewhat favorable and fewer wetland issues exist and a few additional developments will likely be built quite close to the Lake, but not many.

Lake Management Planning and Lake-use oversight. The Utah Lake Commission, formed in 2007, is an authorized, recognized, representative body that promises to help give long term uniformity and continuity in addressing Utah Lake planning and use issues. The Commission is pivotal in generating wise consensus on Lake use and management issues and in funding important studies. The Commission's initial Lake master plan was formally signed on June 26, 2009. This Plan, hopefully with periodic updates, will be extremely valuable in helping to use the Lake wisely. Although the Commission is only a coordinating body, it has broad support and representation from most cities and agencies in the area, including local, county, state and Federal management and regulatory entities.

Background Notes:

Perspectives on water quality. Various perspectives exist as to the meaning of "water quality" Confusion often results from various differing perceptions as to what constitutes water quality.

Briefly, water quality and pollution, as used in agency water programs, relate to the **designated beneficial uses** of a body of water or water source (designated beneficial uses are established by states or EPA via professional staff evaluation and analysis, and adopted after public hearings and official publication). Water quality issues typically relate to whether quality parameters used to measure quality acceptability for designated uses are being violated, and if so, how often, how persistent, etc.

This approach means that water quality it not measured as compared to an absolute good-bad reference level but rather it is measured relative to its designated uses. E.g., suppose a water source is designated as drinking water, but pollution-indicator bacteria persistently show up in samples. The water would then be considered polluted and of poor quality as a drinking water even though it may be of excellent quality for most other beneficial uses. Likewise, a water source might be of good quality for a warm water fishery but unacceptable for many other uses.

In addition to this beneficial-use orientation in defining water quality, there are also non-degradation clauses in water quality laws to help prevent pollution—these clauses are aimed at preventing water quality deterioration when the existing quality is better than required by designated beneficial uses.

Official designated beneficial uses for Utah Lake:

Beneficial Use Designation	Use Description
2B	Protected for secondary contact recreation such as boating, wading, or similar uses.
3B	Protected for warm water species of game fish, including the necessary aquatic organisms in their food chain.
3D	Protected for other aquatic wildlife.
4	Protected for agricultural uses including irrigation of crops and stock watering.

See the state code for more details, water classifications, and associated water quality and pollution parameters.

Total Dissolved Solids (TDS). The TDS parameter is a general classifying parameter in water quality management—in addition to having specific limits for some beneficial uses. Typically, TDS levels increase as one looks at alpine lakes (typically 50-100 mg/l) to mountain streams, rivers, and lakes (100-400 mg/l) to lowland rivers and lakes (400-2000 mg/l) to oceans (30,000-40,000 mg/l) to salt lakes (200,000-400,000 mg/l). TDS limits or guidelines are typically 1000 mg/l for drinking water, 1200-1500 mg/l for irrigation, and 2000-2500 mg/l for livestock watering. A healthy person could survive on water containing as much as 10,000-15,000 mg/l TDS although it might taste rather nasty—It is at about these levels that the human body needs more water to flush out the consumed salts than is being drunk and dehydration ensues—drinking only water more salty than about 15,000 mg/l leads to serious health problems or death.

The current Utah TDS standard for irrigation water is 1200 mg/l. The types of crops and irrigation practices determine TDS levels in irrigation water at which crop damage becomes a significant problem. For the crops and irrigation practices commonly used in Utah, TDS begins to cause noticeable crop damage when TDS is above about 1500 mg/l.

Phosphorus. Phosphorus is a necessary nutrient for plant growth and a major ingredient in most fertilizers. In aquatic systems, excessive phosphorus becomes a problem when it over-stimulates algae and other plants to such heavy growth that water quality and habitat problems result. In the Utah Water Quality Code, "pollution-indicator" threshold values for phosphorus are 0.050 mg/l in flowing waters and 0.025 mg/l in ponded water. Very high levels of phosphorus and other nutrients are common in sewage and many other wastewaters—elevated levels can even be found in natural waters in many cases; particularly in valley-bottom settings when the upstream drainage-basin geology is rich in phosphorus, as is the case for some of the Utah Lake drainage. Nutrients are not significantly removed by conventional wastewater treatment plants. Advanced treatment units for specific parameters are usually very expensive.

Nitrogen. Nitrogen is also a necessary nutrient for plant growth and the major ingredient in most fertilizers. The N/P weight ratio in most plants is about 10 to 1. Nitrogen levels as related to possible excessive algal or other plant growth are generally not found in water quality standards since the bioavailability of various nitrogen species in water and interaction with atmospheric nitrogen raise difficult issues on sources, controllability, and reasonable levels that elude structuring it into reasonable "standards" form. Often in lakes when nitrogen or phosphorus availability is actually limiting to algal growth, control of phosphorus is preferred since relatively low nitrogen availability often encourages growth of "nitrogen-fixing" cyanobacteria (often referred to as blue-green algae). Cyanobacteria are more troublesome than most other algae, in that they often occur in massive blooms and produce poisonous toxins that sometimes result in serious water quality problems. It is important to note that if nitrogen and phosphorus are not at growth-limiting levels, then one must be reduced to that level in order to begin to limit algae growth—assuming that they are the controlling "limiting factors."

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His research and public service activities have included many multidisciplinary studies and evaluations of Utah Lake. He is the developer of the LKSIM model; this computer model simulates the water and salt balances for Utah Lake. He served as member and then chair of the Provo Metropolitan Water Board for many years. He is a consultant to both public and private entities on Utah Lake matters.

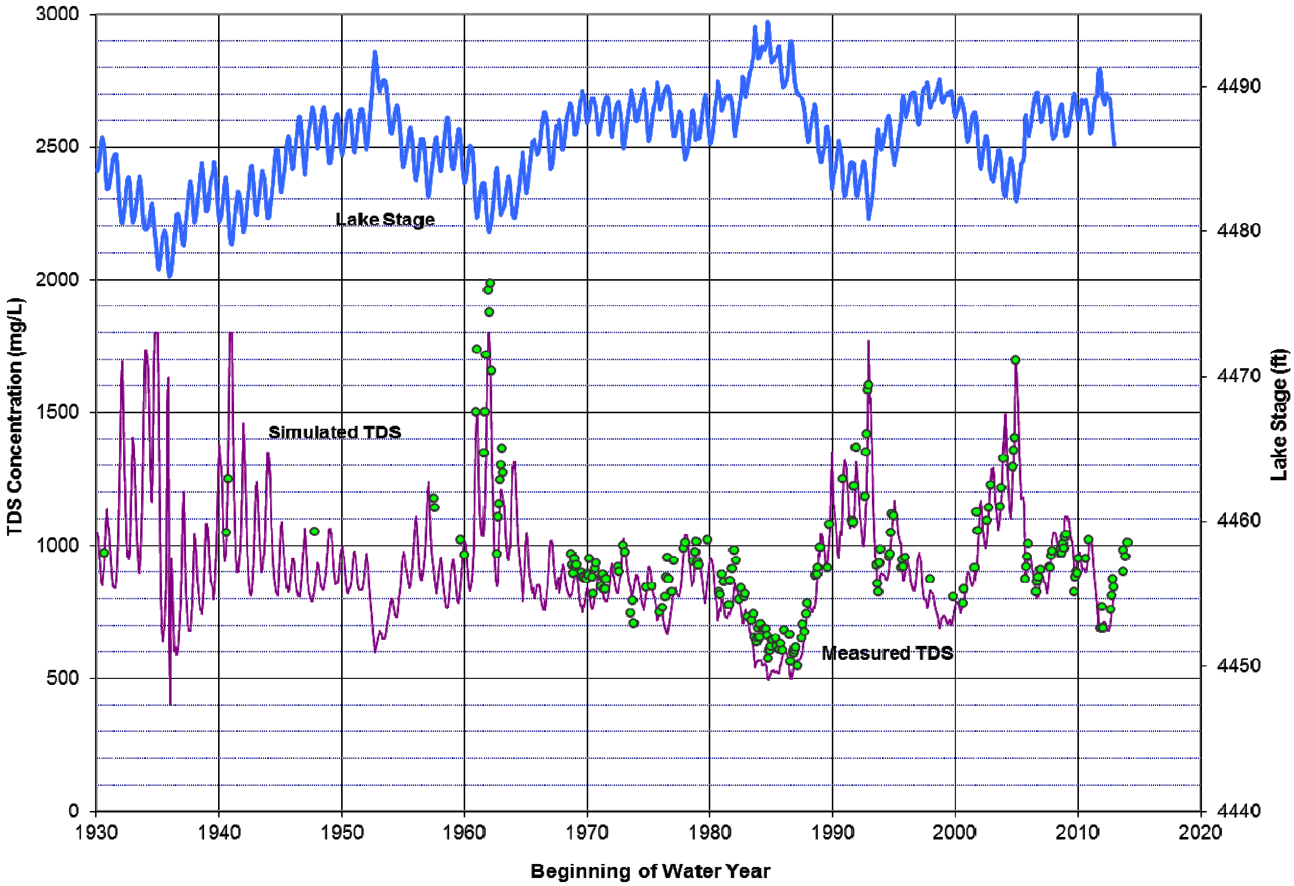
The table and figure on the following two pages are summary results from the LKSIM simulation model that simulates water balance and salt concentrations in Utah Lake.

Table 1: Utah Lake-Avg. water & salt quantities-**1930-2013 Hist. simulation** (83 yr)

	Flow	Inflow		Salts---Percent of the Total Input							
	af/yr	%[1]	%[2]	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4
I. **INFLOW**											
1. **Surface Inflow**											
a. Mountain Strms	228385.	42.7	36.3	23.0	10.9	32.9	27.4	12.7	9.8	35.1	20.5
b. Wastewater Trt	27346.	5.1	4.3	4.1	3.6	4.6	3.8	5.5	3.4	5.7	2.9
c. Other—Main Lake	116231.	21.7	18.5	20.8	15.8	20.8	28.2	22.0	11.9	25.6	22.6
d. Other—Provo Bay	62519.	11.7	9.9	10.3	6.3	13.5	12.0	8.4	4.6	12.8	13.2
e. Other—Goshen Bay	6134.	1.1	1.0	5.7	10.6	1.1	3.9	6.6	9.9	1.5	6.0
1. Sub-Total	**440615.**	**82.4**	**70.1**	**63.8**	**47.1**	**73.0**	**75.3**	**55.0**	**39.5**	**80.7**	**65.2**
2. **Fresh Groundwater**											
a. Main Lake	34396.	6.4	5.4								
b. Goshen Bay	33915.	6.3	5.4								
2. Sub-Total	68311.	**12.8**	**10.8**	**9.5**	**8.1**	**10.4**	**12.9**	**11.1**	**7.9**	**11.8**	**9.6**
3. **Thermal/Mineral GW**											
a. Main Lake	24233.	4.5	3.9	26.1	43.8	16.4	11.6	33.2	51.6	7.3	24.6
b. Goshen Bay	1365.	0.3	0.2	0.5	1.0	0.3	0.2	0.6	0.9	0.2	0.7
3. Sub-Total	**25598.**	**4.8**	**4.1**	**26.6**	**44.8**	**16.6**	**11.8**	**33.8**	**52.5**	**7.5`**	**25.3**
1 + 2 + 3 Sub-Total	**534523.**	100.0	84.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4. **Precipitation**											
a. Main Lake	65358.										
b. Provo Bay	5675.										
c. Goshen Bay	26740.										
4. Sub-Total	**97774.**		**15.5**								
Inflow Total:	**628895.**		100.0								
II. **Outflow**											
1. **Jordan River**	**304290.**	**48.0**									
2. **Evaporation**											
a. Main Lake	221320.	35.2									
b. Provo Bay	16043.	2.5									
c. Goshen Bay	88916.	14.1									
2. Sub-Total	**326279.**	**52.0**									
Outflow Total:	**630579.**	100.0									
Lake storage:	-1684.										
Net:	628895.										
				TDS	Na	Ca	Mg	K	Cl	HCO3	SO4
Ratio: Total Salts Out/Salts In (%)				**71.8**	**98.0**	**35.7**	**97.7**	**98.3**	**98.3**	**45.3**	**98.0**

[1]Based on Total w/o precipitation. [2]Based on Total Including precipitation

Table data from LKSIM model simulation of historical conditions in Utah Lake.



Historical Total Dissolved Solids and Water Levels in Utah Lake

Figure 1.